Fibers **2015**, *3*, 197-205; doi:10.3390/fib3030197

OPEN ACCESS

fibers

ISSN 2079-6439

www.mdpi.com/journal/fibers

Article

An *in vitro* Evaluation on a Novel Root Canal Cleansing Method by Using Nylon Fibers

Shiqian Gao [1], James Kit-Hon Tsoi [1,*], Gary Shun Pun Cheung [2] and Jukka Matinlinna [1]

[1] Dental Material Science, Faculty of Dentistry, University of Hong Kong 4/F, Prince Philip Dental Hospital, 34 Hospital Road, Hong Kong 999077, China; E-Mails: gaoshiqianwh@163.com (S.G.); jpmat@hku.hk (J.M.)

[2] Endodontics, Faculty of Dentistry, University of Hong Kong 3/F, Prince Philip Dental Hospital, 34 Hospital Road, Hong Kong 999077, China; E-Mail: spcheung@hku.hk

* Author to whom correspondence should be addressed; E-Mail: jkhtsoi@hku.hk; Tel.: +852-2859-0303; Fax: +852-2548-9464.

Academic Editor: Jack Gillespie

Received: 1 June 2015 / Accepted: 23 June 2015 / Published: 2 July 2015

Abstract: Despite traditional metal-based dental files, such as NiTi being demonstrated effective in root cleaning, the tooth structure is always damaged. Thus, to fulfill the need for a minimally invasive tool for contemporary endodontics and dentistry, the use of polymer fibers might provide a good option, as it is soft, fabricable, and disposable. In this study, two types of nylon fibers with respective average diameters of 206.9 μm (fiber W) and 156.4 μm (fiber B), respectively, were used as dental files, and mounted onto either a reciprocating or a low-speed rotary hand-piece. *In vitro*, simulated root canal models were colored red using nail varnish, and then cleaned by the fiber files mounted on the hand-pieces. Three parts of the simulated models, *i.e.*, the apical third, the medium third, and the coronal third, were chosen to assess the cleaning the efficiency (CE) of each specimen by calculating the ratio of the cross-sectional area changes, before and after cleansing, using micro-Computer Tomography (CT). A NiTi file with a low-speed hand-piece was used as a control. SEM was used to observe the nylon fiber surfaces before and after the cleansing. Micro-CT results showed that for both the nylon fibers, W and B, an average CE of 82.11% ± 9.68% for the medium third could be achieved, which is statistically higher ($p < 0.01$) than the coronal third and apical third. The cleansing efficiency was not affected by, the types of fibers, nor the hand-pieces according to student's *t*-test. Most of the nylon fibers could withstand deformation after the cleansing. To conclude, nylon fiber files have demonstrated a certain cleansing efficiency in simulated root canals, and micro-CT is a promising method to assess CE.

Keywords: dental hand-piece; files; dental fiber; micro-CT; endodontics; root canal cleaning efficiency

1. Introduction

In dentistry, the specialty dealing with root canals is endodontics. Root canal preparation is the most essential part in root canal treatment (RCT). The preparation aims to clean all inflamed tissues, disinfect the root canal system, and provide a regular-shaped canal that can be sealed from bacteria by using the appropriate filling materials. In fact, cleaning and shaping are not totally separate procedures. To provide sufficient space for obturating materials, the cutting of infected dentine and residual pulp tissue are usually occurring at the same time. Various kinds of hand and rotary endodontic instruments are used routinely in the preparation [1].

Results have shown that mechanical instrumentation is capable of greatly reducing the amount of microorganisms remaining in a root canal system [2]. Furthermore, mechanical cleaning has also been shown as a method that could reduce bacteria without any endodontic irrigant [3,4]. However, despite a good cutting efficiency, the drawback of metal instruments, such as those made of stainless steel, is obvious and not rare in clinic. Iatrogenesis is a negligent adverse effect or complication, which is commonly resulted from medical treatment or device. In endodontics, as mechanical cleaning could be achieved by instrumentation, several kinds of iatrogenic damages might be caused in a clinical procedure. Some studies have described several kinds of potential iatrogenic damages that could occur during root canal preparation with conventional stainless steel instruments. We suggest, for example, zip, elbow, ledging, perforation, outer widening, damage of the apical foramen, and blockage of the root canal system [5–8].

In general, fiber-based materials find many applications in contemporary dentistry [9]. In particular, nylon, which is a synthetic aliphatic polyamide, is a relatively soft material and it has been used in endodontics as a canal brush [10]. One study focused on evaluating the removal of a smear layer by using a new kind of CanalBrush, and it was reported that the CanalBrush was more effective in the narrow parts of the root canal, e.g., apical and middle area, where it could have a better contact with the root canal wall [10].

The objective of this laboratory study was to develop and study a novel way of root canal cleaning, proposed by the authors, which could overcome some safety issues present in traditional endodontic treatment, as mentioned above. We hypothesize that the cleaning efficiency of nylon fibers, using various hand-pieces, would be the same as NiTi files, and would not damage root canals.

2. Experimental Section

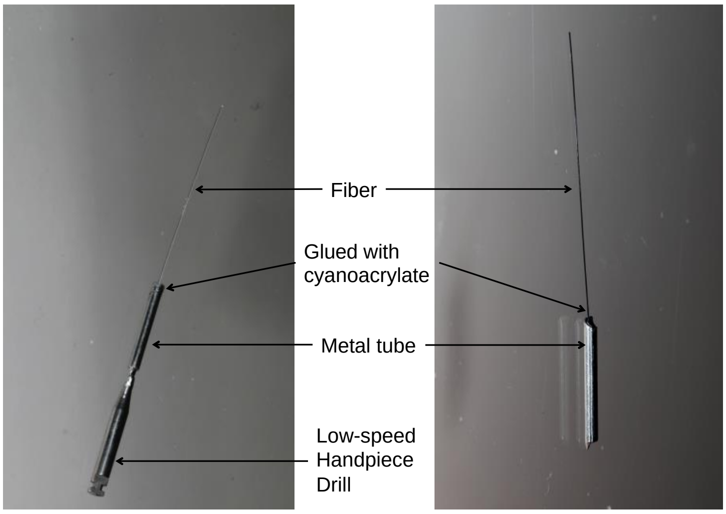
Two nylon fibers, "fiber W" and "fiber B", were purchased and used in this study. Fiber W and fiber B had had average, pretested diameters of 206.90 ± 1.94 μm and 156.40 ± 1.08 μm, respectively. Nine fiber samples from each of the fiber types were carefully examined by using a scanning electron microscope (SEM) (Hitachi S-3400N VP-SEM, Hitachi High Technologies Europe GmbH, Krefeld, Germany) before their use in the experiments. The images were kept on record for further contrast and comparison. These pretested fibers were preserved and used to make fiber files. All the fibers used in this experiment were further investigated using the same SEM, to visually check if any damage or deformation occurred in the fibers after the cleansing.

Another six of each fiber W and fiber B specimens were randomly selected and tested under tension mode. One end of the fiber was fixed and the other end clamped in a U-style jig, and tested using a universal testing machine (ElectroPuls E3000, Instron, UK). A load was applied to the U-style jig, with a constant cross-head speed of 1 mm/min. Then, the dimensional change of the fibers and the load applied were recorded and output was calculated using the Instron software.

Two identical transparent poly(methyl methacrylate) simulated root canal blocks were used. Each block contained a single straight root canal with a length of 20 mm. Prior to dye application, the root canals in the blocks were shaped by dental K files, from 10# to 30#, to confirm that the original shape of the root canal was relatively regular. Then, distilled water was used to wash, and rinse out the debris. After that, both simulated root canal blocks were placed into a centrifuge (Heraeus Primo/Primo R Centrifuge, Hanau, Germany) to discharge the residual water in order to keep the specimens dry. Next, each root canal was colored and filled with red nail polish (No. 470 ANNA SUI, New York, NY, USA) using a plastic syringe (Insulin syringe ½ cc, Terumo, Japan). Because the nail polish liquid was too viscous to flow easily, in order to ensure the completeness of the coloring, the same centrifuge was used to fully fill the whole root canal with the nail polish. The procedure was, in brief, as follows: first, the nail polish liquid was filled into a root canal in the acrylic block using a needle. Then, the simulated root canal was fixed in a 50 mL centrifuge tube (Tube 1). In order to keep the centrifuge balanced, Tube 1 was weighted using a laboratory balance, and another tube (Tube 2) was filled with deionized water to provide an equal mass to Tube 1. Next, these two tubes were then inserted into the centrifuge, which was then operated at a speed of 1000 rpm for 1 min. The aforementioned procedures were repeated three times to ensure that the nail polish could fully fill the root canal evenly and completely. Finally, the simulated root canal block was removed from the centrifuge and allowed to polymerize at room temperature for 24 h.

Two hand-pieces were used in this study, a low-speed hand-piece (NSK, Tokyo, Japan, denoted as LH) and a reciprocating EVA hand-piece (ProFin™, W&H, St Albans, UK, denoted as RH). A single fiber with an exposed length of 20.0 mm was fixed, using a cyanoacrylate glue (Aron Alpha, Toagosei, Japan), in a stainless steel metal tube, which had the same outer diameter (2.0 mm) as the hand-pieces (Figure 1). Then, the files were inserted into the hand-piece directly and then activated for 5 min prior to use in a cleaning test to check if they were workable and stable enough.

Before cleaning with the fiber files, a #10 K file was used to achieve access to the acrylic block in order to allow the soft fiber to slide in. Then, the specimens were cleansed with different fiber files with the hand-pieces, including four study groups (i) Fiber W with an RH; (ii) Fiber B with an RH; (iii) Fiber W with an LH; and (iv) Fiber B with an LH. One simulated root canal specimen was prepared using a NiTi file (ProTaper, Dentsply, Weybridge, UK) with the low-speed hand-piece, and this served as the control. Each acrylic block specimen was drilled separately, using these four hand-pieces, and the protocol was 15 s, 10 times per simulated root canal.



(**a**) (**b**)

Figure 1. Custom-made fiber files used in this study for the low-speed hand-piece (**a**) and for the reciprocating EVA hand-piece (**b**). Note: An adaptor was used to connect the low-speed hand-piece to the metal tube.

Cross-sectional images of the cleaned simulated root canal specimens were obtained by scanning using a micro-CT (Skyscan 1172, Bruker, Brussels, Belgium) at the apical third, the medium third, and the coronal third parts. It was observed that 24 to 48 h was needed to scan each specimen. Then, the remaining nail-polish-derived dye in the canal blocks was cleansed and washed out using acetone and the blocks were prepared for the next test.

The dye was expressed as a white color in the image, before and after the cleansing, because of the light reflection. After the cleansing, when the dye was removed, no reflection of light occurred and, thus, a black color was observed. All the black and white areas were evaluated by using the micro-CT software, before and after the cleansing. Then, the cleansing efficiency (CE), expressed in percentage, was evaluated by:

$$CE = \frac{Area\ of\ black\ (after\ cleansing)}{Area\ of\ white\ (before\ cleansing)} \quad (1)$$

Student's *t*-test was used to analyze whether the types of fiber and hand-pieces, respectively, might give any statistical significance to the cleansing. One-way ANOVA was used to analyze the average cleansing efficiency between the cleansing areas. All the descriptive statistics and statistical analyses were done at $\alpha = 0.05$ using Microsoft Excel 2010 (Microsoft, Redmond, WA, USA).

3. Results and Discussion

3.1. Tensile Test and SEM Evaluation

In the tensile test, both, nylon fiber W and fiber B, showed good elastic properties, as the relationship between load applied to the fiber and its strain were almost linear. The average maximum load that could be applied to nylon fibers W and B were 10.48 ± 1.44 N and 3.17 ± 0.42 N, respectively. Fiber W has an average modulus of elasticity of 779.3 MPa, whilst 281.3 MPa was revealed for fiber B. Low stress resulted in a larger deformation of nylon fiber B, and it was also observed that nylon fiber B could not be ruptured completely in this tensile test. Thus, even though some of nylon fiber B had been broken up, the testing machine was still able to test it until the end of set length and then it stopped recording.

According to the SEM measurements (Figure 2a,b), the shape of each fiber, observed under the microscope, was straight and regular with a smooth surface, which was considered acceptable in the current study. All fibers exhibited a smooth surface (Figure 2c,d) after cleansing. All nylon fiber W specimens were smooth, as they were in the beginning, without any obvious deformation. However, some parts of the fibers were covered by residual nail polish. For the nylon fiber B specimens, the observed situation was similar to that of nylon fiber W, except for one fiber that was split (Figure 2e).

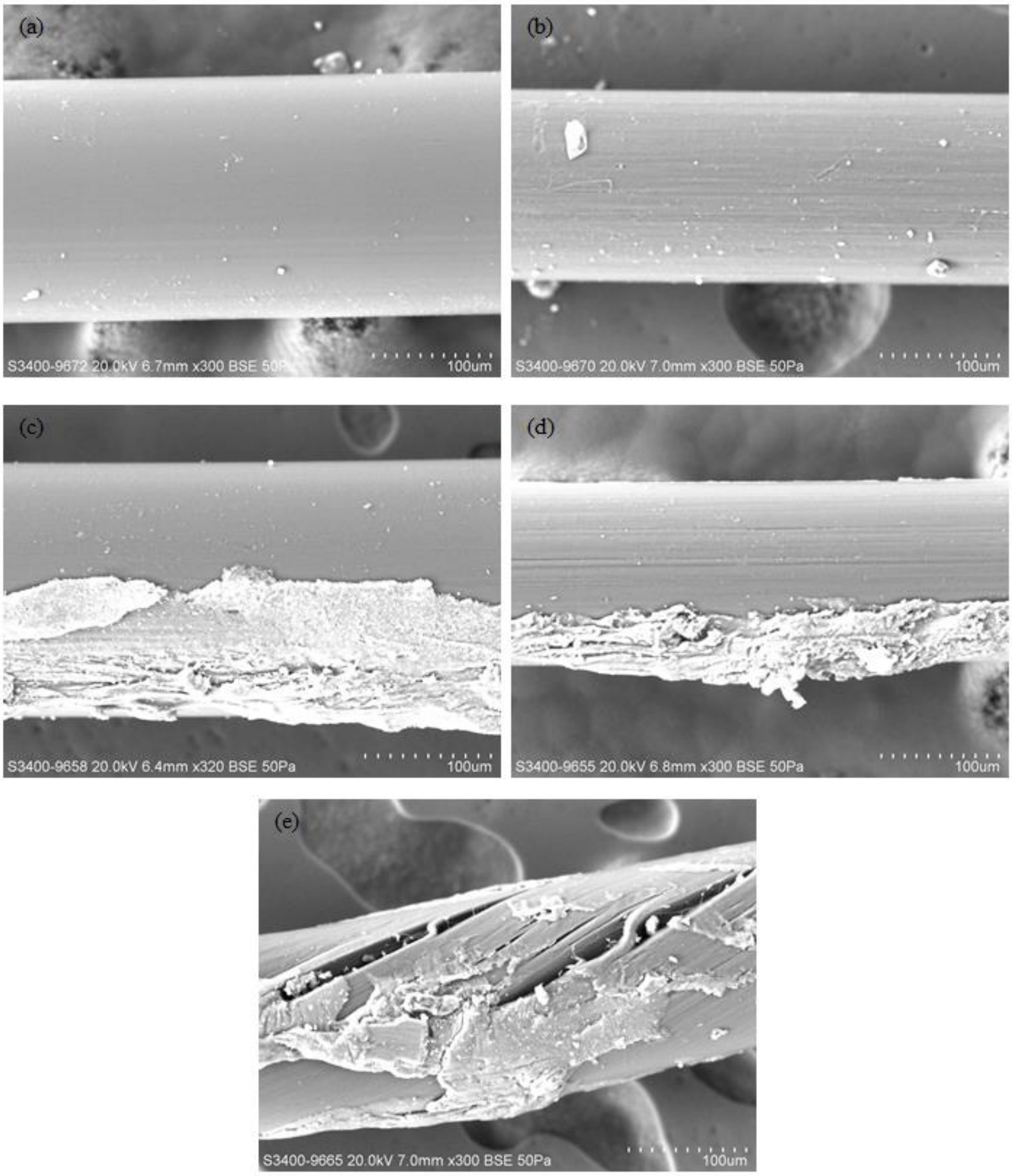


Figure 2. SEM showing the nylon fiber before and after the cleansing: (**a**) fiber W before use; (**b**) fiber B before use; (**c**) fiber W after use; (**d**) fiber B after use; (**e**) split fiber B after use.

In addition, it is noteworthy that such a system is also a type of brushing procedure, lacking any cutting effects. During the cleansing, the fiber file could adapt itself to the canal shape, unlike those of rigid metal alloy files, which may fracture in the narrow root canal tip. Even one fiber specimen for nylon B was split, none of the other fibers has shown a complete rupture and only fiber deformation was observed. Thus, we may conclude that the fiber would be quite safe to use as a file. At least, it would probably not fracture and remain in any part of the root canal system.

3.2. Micro-CT and CE Evaluation

Figures 3 and 4 show the representative cross-sectional change of micro-CT scanning, before and after cleansing, using fiber files and a control NiTi file, respectively. The average CE in the three cross-sectional areas, the apical third, the medium third, and the coronal third, were evaluated. There were four groups, including both the reciprocating EVA hand-piece (RH) and the low-speed hand-piece (LH), with both the fibers, B and W. These CE are presented in Table 1.

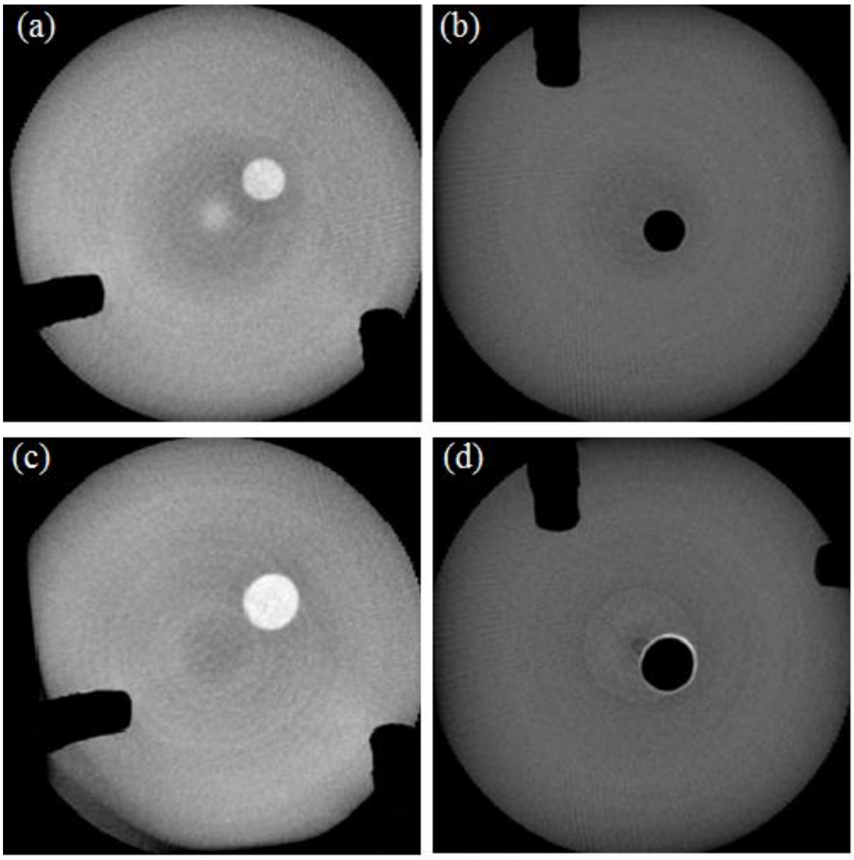


Figure 3. Representative micro-CT scanning of simulated root canal with nail varnish, before and after cleansing, using fiber file on medium third, before (**a**) and after (**b**) the cleansing, and on coronal third, before (**c**) and after (**d**) the cleansing. White area shows the nail polish reflection, and black area shows the cleansed portion.

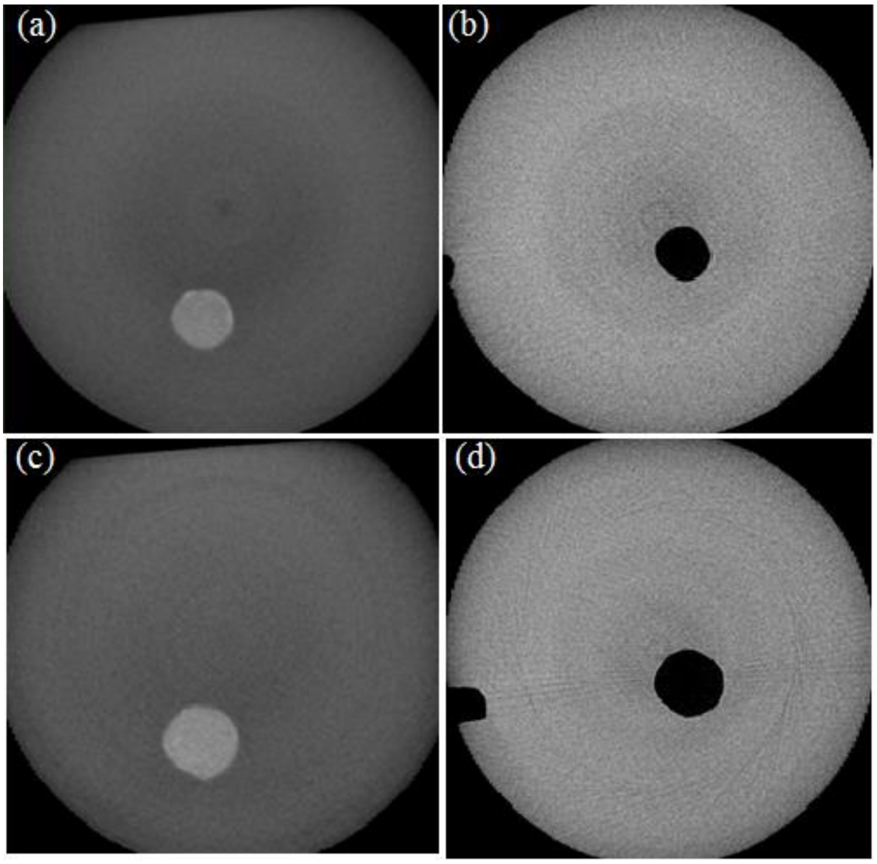


Figure 4. Representative micro-CT scanning of simulated root canal with nail polish, before and after cleansing, using a NiTi file on the medium third, before (**a**) and after (**b**) the cleansing, and on the coronal third, before (**c**) and after (**d**) the cleansing. N.B. Root canal enlargement was observed in (**b**) and (**d**).

Table 1. Average cleansing efficiency (CE) (as cleansing percentage) of various groups.

Group	Apical Area (%)	Medium Area (%)	Coronal Area (%)
(i) RH + W	33.64	80.06	57.01
(ii) LH + W	38.54	95.77	61.07
(iii) RH + B	0	72.93	56.10
(iv) LH + B	39.83	79.69	65.69
Mean ± SD	28.00 ± 18.86	82.11 ± 9.68	59.97 ± 4.39

For the control NiTi group, no remaining nail polish was observed in both the apical third and the medium third of the root canal, whereas the CE was >100% due to the enlargement of the root canal, *i.e.*, it damaged the root canal. One-way ANOVA revealed that the average CE in all parts are statistically different (p ~ 0.00077), with the medium third (82.11% ± 9.68%) being statistically higher than the coronal third (59.97% ± 9.73%, p ~ 0.00089) and apical third (28.00% ± 18.86%, p ~ 0.0053). Given this, the student's *t*-test showed that the types of hand-pieces (p ~ 0.32) and fiber (p ~ 0.52) did not, statistically, significantly affect the CE. It could be substantiated that the fibers, in general, provide a higher cleaning efficacy in the medium part. This might be due to the following facts: (1) the work delivered from hand-piece to fiber is higher at the medium and top parts of the fiber than at its bottom part; (2) with the limitations of space available in a root canal, a faster motion resulted in a higher surface contact between the fiber and the canal. This means that the friction between the varnish and the fiber would also be high. This would show and suggest a better root canal brushing efficiency.

The lowest CE was observed in the apical third. Theoretically, in the case of the narrowest canal, most of the work was allocated to the fiber. This said, the apical part, supposedly, could induce the highest cleaning efficiency. However, the fact is the opposite is true due to the centrifugal force. According to centrifugation theory, rotors running at the same rotational speed with different diameters will have different accelerations [11]. Under the influence of a centrifugal force, the nail polish debris remaining in the canal had a tendency to ascend to the upper part of the canal. As the current experiment was under dry conditions, that is to say, no irrigant was used during the cleansing, the debris could not be washed out. As a consequence, the debris remained in the root canal. Thus, in the next study, e.g., some water and endodontic chemicals, such as sodium hypochlorite and hydrogen peroxide, could be added to simulate, more accurately, the clinical conditions, demonstrating safety, since the interaction between nylon fibers and chemicals are unknown, and, finally, perhaps improve the cleansing efficiency.

4. Conclusions

A novel dental nylon fiber files have been demonstrated to have good elasticity and flexibility with a certain cleaning efficacy without damage to a simulated root, but not the same efficiency as the NiTi file. Thus, the hypothesis should be partially rejected. With the different hand-pieces and nylon fibers, and the limitations of this laboratory study, the investigated and developed combined system showed and suggested a cleansing efficiency (CE), particularly in the medium part of the simulated root canal, without any damage of the simulated root canal using the micro-CT method. Despite the small sample size in the study group of the current study, the specimen preparation and the fiber system seemed to set a good foundation and justification for future studies.

Acknowledgments

The authors acknowledge no conflicts of interest. This work was done in partial fulfillment of the requirements for the degree of MSc (DMS) for the first author, at the Faculty of Dentistry, The University of Hong Kong.

Author Contributions

The manuscript was finalized through contributions from all authors, and all authors approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Tronstad, L. *Clinical Endodontics: A Textbook,* 3rd ed.; Thieme, Stuttgart: Stuttgart, Germany, 2009.
2. Baugh, D.; Wallace, J. The role of apical instrumentation in root canal treatment: A review of the literature. *J. Endod.* **2005**, *31*, 333–340.

3. Bystrom, A.; Sundqvist, G. Bacteriologic evaluation of the efficacy of mechanical root canal instrumentation in endodontic therapy. *Eur. J. Oral. Sci.* **1981**, *89*, 321–328.
4. Mallineni, S.K.; Nuvvula, S.; Matinlinna, J.P.; Yiu, C.K.Y.; King, N.M. Biocompatibility of Various Dental Materials of Contemporary Dentistry: A Narrative Insight. *J. Investig. Clin. Dent.* **2013**, *4*, 9–19.
5. Weine, F.S.; Kelly, R.F.; Lio, P.J. The effect of preparation procedures on original canal shape and on apical foramen shape. *J. Endod.* **1975**, *1*, 255–262.
6. Weine, F.S.; Kelly, R.F.; Bray, K.E. Effect of preparation with endodontic handpieces on original canal shape. *J. Endod.* **1976**, *2*, 298–303.
7. Glickman, G.N.; Dumsha, T.C. Problems in canal cleaning and shaping. In *Problem Solving in Endodontics*, 3rd ed.; Mosby: St Louis, MO, USA, 1997; pp. 91–122.
8. Hülsmann, M.; Peters, O.A.; Dummer, P.M. Mechanical preparation of root canals: Shaping goals, techniques and means. *Endod. Top.* **2005**, *10*, 30–76.
9. Zhang, M.; Matinlinna, J.P. E-glass fiber reinforced composites in dental applications. *Silicon* **2012**, *4*, 73–78.
10. Garip, Y.; Sazak, H.; Gunday, M.; Hatipoglu, S. Evaluation of smear layer removal after use of a canal brush: An SEM study. *Oral. Surg. Oral. Med. Oral. Pathol. Oral. Radiol. Endod.* **2010**, *110*, e62–e66.
11. Berman, A. Theory of centrifugation: Miscellaneous studies. *J. Natl. Cancer Inst. Monogr.* **1966**, *21*, 41–76.